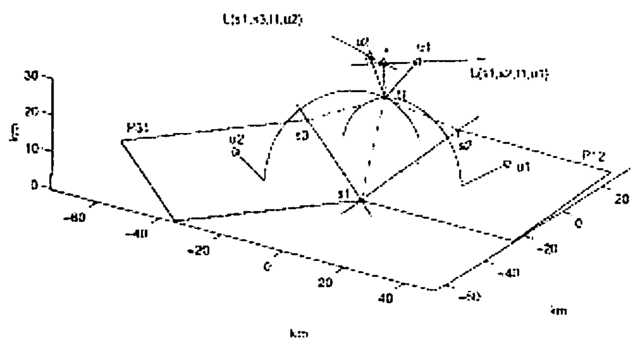
Method for determining position and velocity of targets from signals scattered by the targets

Patent number: SE519088
Publication date: 2003-01-07
Inventor: HERBERTHSON MAGNUS
Applicant: TOTALFOERSVARETS FORSKNINGSINS [SE]
Classification:
- international: G01S13/00; G01S13/87
- european: G01S13/00B; G01S13/87E
Application number: SE20010001662 20010511
Priority number(s): SE20010001662 20010511

Also published as:
WO02093191 (A1)
EP1402282 (A1)
US2004135718 (A1)
SE0101662 (L)

Abstract not available for SE519088
Abstract of corresponding document: **US2004135718**

The present invention relates to a method for determining position and velocity of targets from signals scattered by the targets. One uses a first and a second station comprising transmitter/receiver (s1,s2) of electromagnetic or acoustic signals and carries out mono-static measurements (M1,M2) from each station, and also a bi-static measurement between the stations (B12), and calculates first through the two mono-static measurements a number of target candidates with 2-dimensional position and 2-dimensional velocity, whereupon these are tested against the result of the bi-static measurement and the target candidates which are found In all measurements with suitable error margins are retained.



(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
21 November 2002 (21.11.2002)

PCT

(10) International Publication Number
WO 02/093191 A1

(51) International Patent Classification[7]: G01S 13/00, 13/87

(21) International Application Number: PCT/SE02/00894

(22) International Filing Date: 8 May 2002 (08.05.2002)

(25) Filing Language: Swedish

(26) Publication Language: English

(30) Priority Data:
0101662-5 11 May 2001 (11.05.2001) SE

(71) Applicant (for all designated States except US): TOTALFÖRSVARETS FORSKNINGSINSTITUT [SE/SE]; S-172 90 Stockholm (SE).

(72) Inventor; and
(75) Inventor/Applicant (for US only): HERBERTHSON, Magnus [SE/SE]; Strågatan 21, S-589 55 Linköping (SE).

(74) Agent: FÖRSVARETS MATERIELVERK; Patentenheten, S-115 88 Stockholm (SE).

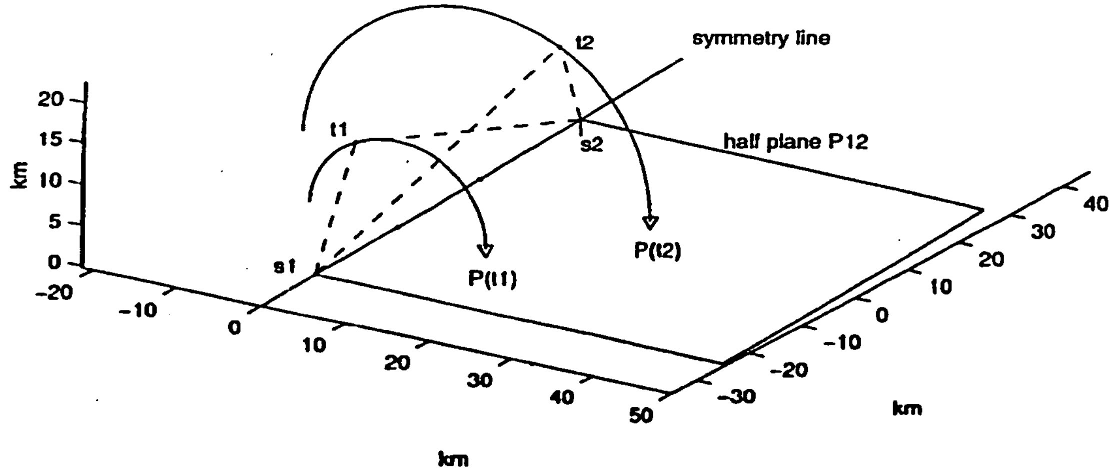
(81) Designated States (national): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZM, ZW.

(84) Designated States (regional): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: METHOD FOR DETERMINING POSITION AND VELOCITY OF TARGETS FROM SIGNALS SCATTERED BY THE TARGETS



(57) Abstract: The present invention relates to a method for determining position and velocity of targets from signals scattered by the targets. One uses a first and a second station comprising transmitter/receiver (S_1, S_2) of electromagnetic or acoustic signals and carries out mono-static measurements (M_1, M_2) from each station, and also a bi-static measurement between teh stations (B_{12}), and aclculated first through the two mono-static measurements a nubmber of target candidates with 2-dimensional position and 2-dimensional velocity, whereupon these are tested against the result of the bi-static measurement and the target candidates which are found in all measurement with suitable error margins are retained.

WO 02/093191 A1

Method for Determining Position and Velocity of Targets from Signals scattered by the Targets

The present invention relates to a method for using signals scattered by one or more targets for determining position and velocity of each target. The invention is especially useful in the case where the positions in space and velocity vectors for a very large number of targets are to be determined. The invention is for instance intended for use with the system for determining position and velocity of targets for which this day a patent has been applied with Hans Hellsten as inventor, and which patent application 0101661-7 is hereby incorporated by reference when regarding a more detailed reasoning of the system of transmitter and receiver, henceforth called stations.

The invention is based on a 3-dimensional position space and a 3-dimensional velocity space, which together form a 6-dimensional state space with up to $\sim 10^{20}$ cells, where in principle each cell shall be assigned the value 0 (no target) or 1 (target). The large number of cells in the state space place special requirements on the signal-processing method, and one possible method is dealt with in said patent application by Hellsten. In the present patent application an alternative method is suggested.

Due to the large number, $\sim 10^{20}$, of cells in the state space, known projection methods are slow and cumbersome. The simplest known method is where all conceivable target positions are formed for three stations and N targets. They will be fewer than N^3 in number, and it is easy to determine position as well as velocity vector for the target for every possible target position. In this way $\sim N^3$ candidates are obtained, each of which is then supported or discarded by further independent measurements. This gives a method of processing which requires $K N^3$ operations. If K is large then this method can be much too slow for interesting values of N.

A specific property of the systems for which the use of the present method is intended is, according to the above, that the information in an introductory, detecting phase can be regarded as binary, which can be utilised. Further the input is from the beginning distributed between different stations. This means that a local, distributed processing which calculates parameters of position and velocity for the

targets gives an advantage, as one then receives a paralleling effect on the sensor-near level. A comprehensive communication between stations is then necessary.

The stumbling block is the association problem, which is to in a correct way pair together data from different radar stations. An association where it is unclear whether it is correct or not can be called a candidate. Gradually it becomes clear whether a candidate is a correct association, that is a target, or a false association, sometimes called a ghost. The problem is then to handle the initially very large number of ghosts, that is to find the targets among all candidates.

The purpose of the invention is to solve this problem, which is done by the invention being given the features that appear from the following independent claim. Suitable embodiments of the invention will be evident from the remaining claims.

The invention will be described in more detail in the following with reference to enclosed drawings, where

fig. 1 shows how the geometry around two stations on a plane and how rotation-symmetrical conceivable target positions on measurement from two stations can be transferred to points on a half-plane,

fig. 2 shows how velocities in a 3-dimensional space can be transferred to non-unique velocities in said half-plane and

fig. 3 shows how one can determine position and velocity by combining measurements from two pairs of stations that have a common station.

If one studies figure 1 with two stations, s_1, s_2, on the ground, which see one and the same target, t_1, in mono-static measurements, one realizes immediately that they place targets along a half-circle in the position space above the ground. Bi-static measurements between the two stations share this symmetry, so that a half-circle can be accepted or discarded in its entirety. For each point on the half-circle, an estimated velocity v is determined up to a line in the velocity space. That is, two stations together ascribe a candidate (target or ghost) a two-surface in the state space. A family of such two-surfaces in the state space form a relatively complicated sub-set in the state space. It is therefore desirable with an introductory calculation where candidates can be represented by points in a reduced state space, rather than by areas. In the case where one studies position as well as velocity, as

described above, the reduced state space will consequently be 4-dimensional. Further some type of candidate reduction should occur in this reduced state space, so that the final processing in the full state space becomes simplified.

The basic idea of the invention is to work in low-dimensional, < 6, state spaces that are common to several sensors. Optimally the areas in the full state space, corresponding to certain sensor registrations, will be represented by points in the lower-dimensional ditto. As the reduced state space is common to several sensors, one can under certain conditions obtain a sensor-near and local elimination of many ghosts by calculations which are not demanding to process. Such a reduced set of candidates, together with other similarly reduced sets of candidates make up input to a final and complete association in the full state space. This final calculation is then, by the relatively small size of input amounts, also surmountable in terms of processing intensity.

From the symmetry in figures 1 and 2 one can see that one can allow the points on the arc corresponding to a candidate t_1 be represented by a point $P(t_1)$ in a half-plane P_{12} on one side of the symmetry axis. In figure 2 one can see how the velocity v can be determined from mono-static and/or bi-static measurements from a pair of stations by Doppler measurements, except for a component in tangent to the arc direction. This means that the velocity lies on the line $L(s_1,s_2,t_1,v)$. All velocities on this line will be represented by the same 2-dimensional velocity u, which is a vector in the half-plane P_{12}. In reverse, it applies that if the velocity in the half-plane P_{12} is known, one knows that the velocity lies on the line $L(s_1,s_2,t_1,u)$, where u is now regarded as the canonic representative of u in three dimensions.

In contrast to the simple problem of finding the common line between measurements from two stations, that is the arc from the intersection of two (half-)spheres, or the common point between measurements from three stations, that is the point of intersection of three (half-)spheres, the common points from two or three bi-static measurements between the same stations are more complicated to find, as each measurement generates a (half-)ellipsoid with the stations at the focal points. It is more difficult to calculate common points between two ellipsoids than between spheres.

The invention utilises therefore mono-static measurements between pairs of stations to calculate candidates. It then uses the associated bi-static measurement to eliminate the ghosts. In this way one does not need to calculate common points based on the ellipsoids, but rather looks only at the points where the mono-static measurements indicate that there are candidates and sees whether the bi-static measurements have one or several candidates at the distance in question. This is much simpler than calculating common points from bi-static measurements. In cases where the distance-based analysis does not give sufficient elimination of the number of ghosts, one can use as well the compiled Doppler information. The Doppler measurements share according to the above the symmetry of the distance measurements and by requiring compatible mono-static and bi-static Doppler measurements a further reduction in the number of ghosts is obtained.

In the following a more detailed description is given of the method in connection with an amount of distributed isotropic transmitters/receivers of electromagnetic or acoustic signals. In the concrete example we consider a number of radar stations. Each radar station sends out a signal that is received by the station itself and also by surrounding neighbours. We refer again to the above-mentioned patent application by Hellsten for a more detailed description of how the system can be embodied in general.

In a first step one uses a first s_1 and a second s_2 transmitter/receiver of electromagnetic or acoustic signals and carries out mono-static measurements M_1 and M_2 from each transmitter/receiver, and also a bi-static measurement B_{12} between the stations. First the two mono-static measurements create a number of candidates with 2-dimensional position and 2-dimensional velocity. Then these are tested against the result of the bi-static measurement and the candidates found in all of the measurements with suitable error margins are retained.

In a second step one carries out corresponding calculations with one of the two original stations, say s_1, and a third station s_3. The same calculations that were carried out for s_1 and s_2 are carried out for s_1 and s_3. One then sorts, for each calculation, conceivable targets according to the distance to the common transmitter/receiver, here s_1, and determines the distance bins in both calculations that simultaneously contain one or several candidates. For these candidates the radial Doppler velocity in the two measurements is studied. If the difference is

smaller than a predetermined value then the candidates are retained; if not then they are discarded.

Figure 3 shows how a target t_1 is represented by a point in the half-plane P_{12} and another in the half plane P_{31}. The 3-dimensional position is given by the point of intersection of the half-circles. The true velocity v for t_1 is represented by the velocity u_1, which is a vector in the plane tangent to the point $P(t_1)$ in the half-plane P_{12} and corresponding vector u_2 in the half-plane P_{31}. Each such velocity can be represented according to the above on a line in the 3-dimensional space. The true velocity v lies in the intersection between these lines $L(s_1,s_2,t_1,u_1)$ and $L(s_1,s_2,t_1,u_2)$.

In a third step one can carry out a third bi-static measurement B_{23} between the two transmitters/receivers, here s_2 and s_3, which is not the common transmitter/receiver according to the above. The result can be used together with the candidates that remain after step two above to further reduce the number of ghosts.

The local treatment around three stations has through this procedure, with initially paired calculations around two stations and then including all three stations in the calculations, in an elegant way requiring relatively few calculations, given a number of targets and possibly, as a consequence of imperfections in the measurement system and the application of it, some remaining ghosts. It is interesting that in parallel with this, in a larger system, a number of other stations can also have given a number of targets. The parallel handling is very favourable and an absolute pre-requisite according to the above for the processing to be at all possible in a larger system with many stations.

To improve the accuracy in the calculations and discard possible remaining ghosts, one can of course allow further stations, which have a sufficient range, to be included in the calculations. One can consider further mono-static as well as further bi-static calculations.

It has already been mentioned several times that the present invention is intended to be included in a larger system of stations, for example that which is presented in the said patent application by Hans Hellsten. In this application it is stated that a number of stations can be placed as grid points in an essentially equidistant grid on a surface, which limits the surveyed state space, e.g. a ground surface. The idea in

the patent application of Hellsten is that the ranges of the stations shall be such that each target is detected on bi-static measurement by at least six independent sets of transmitters and receivers. For this reason the range of the stations is $2d$, if the distance between the stations is d, if we consider an essentially planar surface. If the surface is not essentially planar then the ranges must be adapted so that an at least 6-fold bi-static overlap of the surveyed state space is nevertheless achieved.

Claims:

1. Method for determining position and velocity of targets from signals scattered by the targets, *characterised* in that one uses a first and a second station comprising transmitter/receiver (s_1,s_2) of electromagnetic or acoustic signals and carries out mono-static measurements (M_1,M_2) from each station, and also a bi-static measurement between the stations (B_{12}), and first from the two mono-static measurements calculates a number of target candidates with 2-dimensional position and 2-dimensional velocity, whereupon these are tested against the result of the bi-static measurement and the target candidates found in all the measurements with suitable error margins are retained, whereby the calculations take place in a 2-dimensional position space and a 2-dimensional velocity space and give the position and the velocity modulo rotational symmetry around a line through the two stations (s_1,s_2) in that one utilises that rotational symmetry results in the ability to represent conceivable measured target positions in a 3-dimensional position space, which lies along arcs with centre on the axis of symmetry, by a point ($P(t)$) in a half-plane (P_{12}) on one side of the axis of symmetry, which makes a 2-dimensional position space, and that the velocity can be represented by a velocity in a 2-dimensional velocity space that is a plane tangent to said point.

2. Method according to claim 1, *characterised* in that one establishes the position for a target candidate in a complete 3-dimensional position space and 3-dimensional velocity space through corresponding calculations with either the first or the second station (s_1,s_2) and a third corresponding station (s_3), whereupon for each calculation one sorts target candidates according to distance to the common station and determines for the distances in both calculations which both contain one or several conceivable targets, whether the candidate shall be retained as target or discarded depending on the agreement of the radial velocity.

3. Method according to claim 2, *characterised* in that one carries out a third bi-static measurement (B_{23}) between the two stations (s_2,s_3) which are not the common station according to claim 2 and retains a target candidate if agreement is achieved, otherwise the target candidate is discarded.

4. Method according to claim 2 or 3, ***characterised*** in that one uses additional stations for mono-static and/or bi-static measurements which are compared with the result of the earlier ones.

5. System according to anyone of claims 1 – 4, ***characterised*** in that said stations (s_1,s_2,s_3) are placed as grid points in an essentially equidistant grid on a surface, which limits the surveyed position space, e.g. a ground surface, with the distance between the grid points essentially the same size, *d*, and where the range of the signals when having an essentially planar surface are at least 2*d*, implying at least 6 independent bi-static configurations per grid point and that the range, in the case that the surface is not essentially planar, is adapted to give the same number of bi-static configurations as in the planar case.

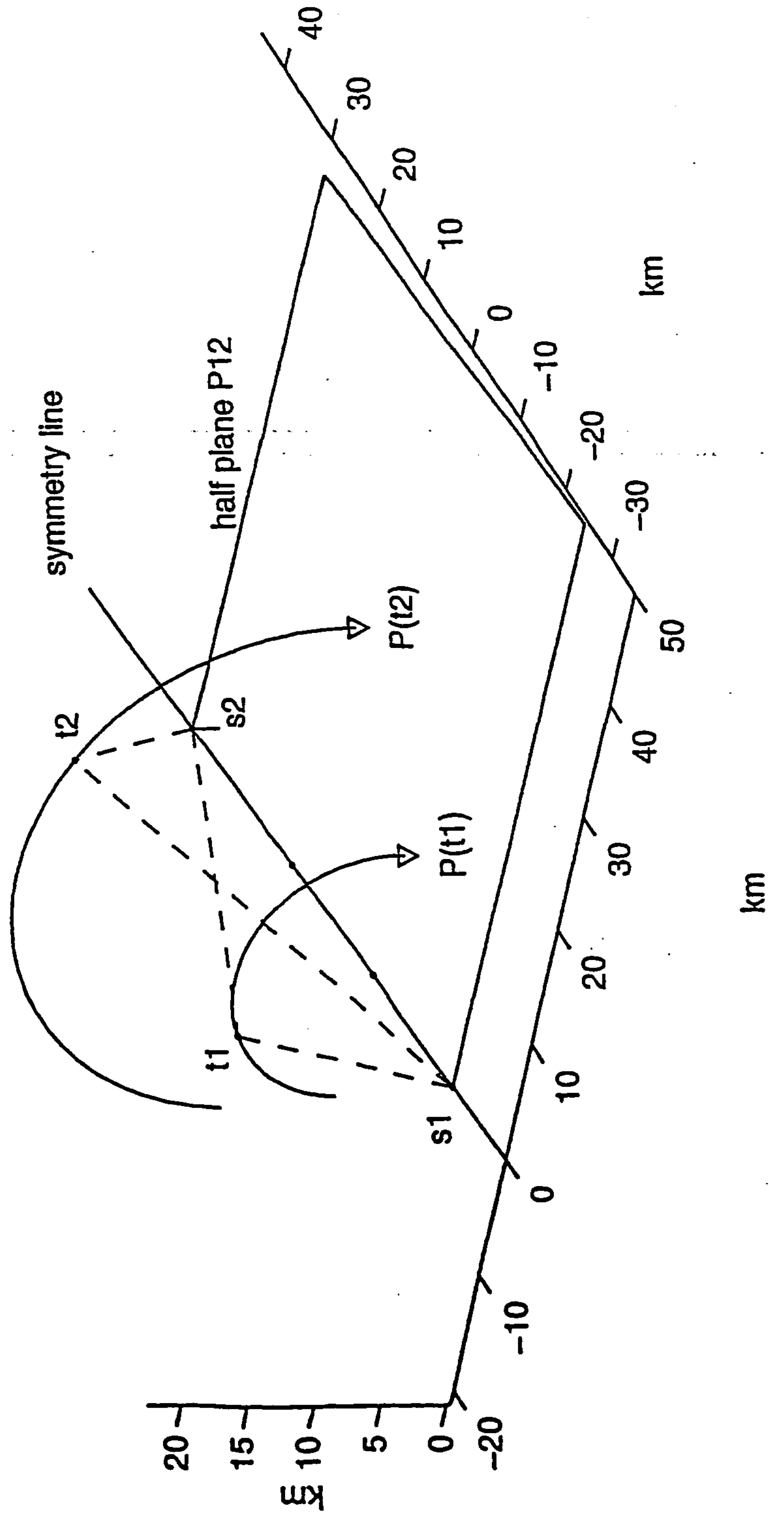

symmetry line
half plane P12
P(t2)
P(t1)
t2
s2
t1
s1
km
km
km
40
30
20
10
0
-10
-20
-30
50
40
30
20
10
0
-10
-20
20
15
10
5
0
-20

FIG 1

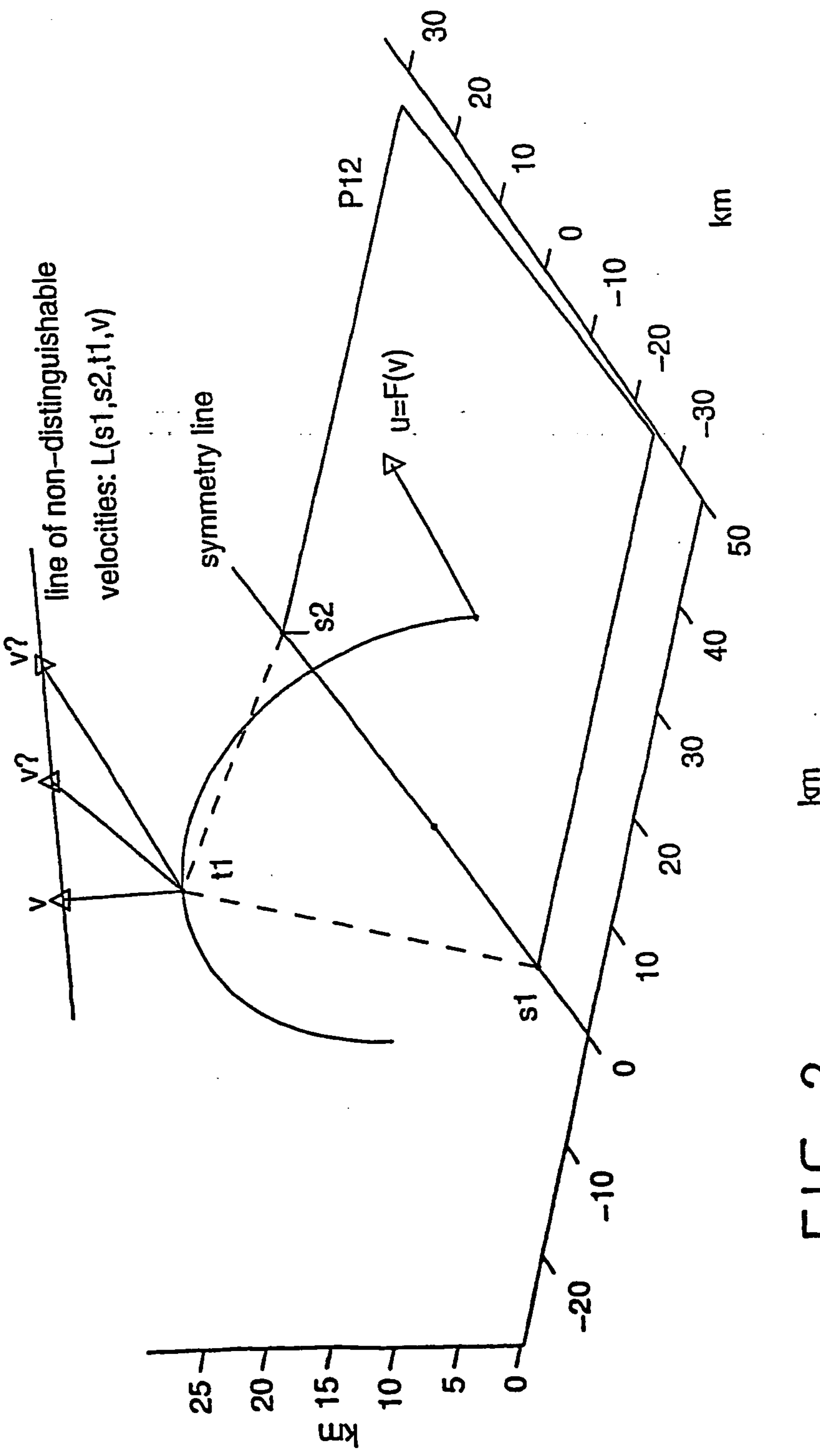

line of non-distinguishable
velocities: L(s1,s2,t1,v)
symmetry line
u=F(v)
P12
v?
v?
v
t1
s1
s2
km
km
km
0
5
10
15
20
25
-20
-10
0
10
20
30
40
50
-30
-20
-10
0
10
20
30

FIG 2

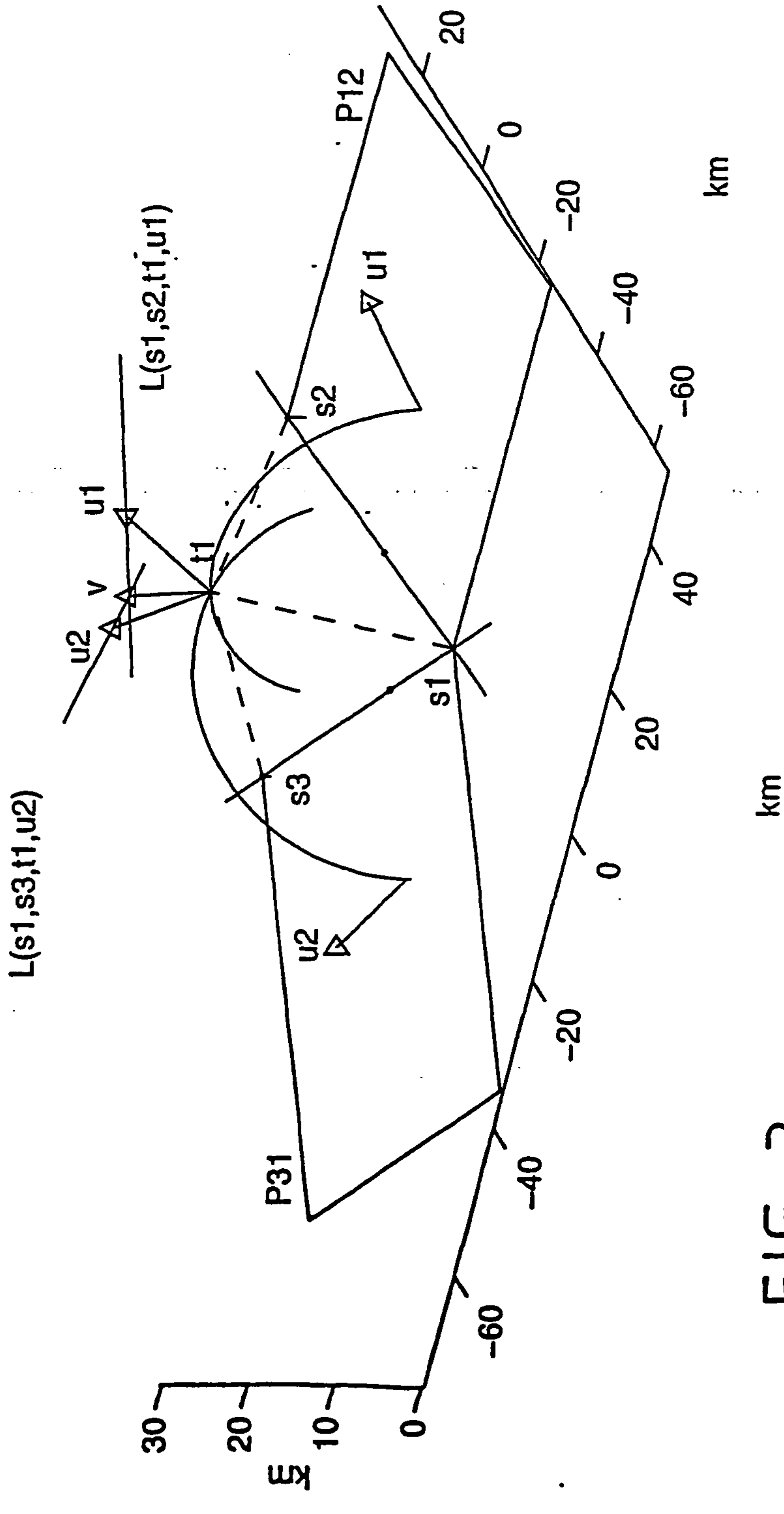

L(s1,s2,t1,u1)
L(s1,s3,t1,u2)
P12
P31
u1
u2
v
t1
s1
s2
s3
km
km
km
-60
-40
-20
0
20
40
-60
-40
-20
0
20
0
10
20
30

FIG 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 02/00894

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: G01S 13/00, G01S 13/87

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: G01S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-INTERNAL,WPI DATA,PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5448243 A (K-H.BETHKE ET AL), 5 Sept 1995 (05.09.95), column 3, line 25 - line 46; column 4, line 3 - line 26; column 5, line 50 - line 52, col.10 li.54-col.11,li.5, abstract --	1-5
A	US 4499468 A (D.M.MONTANA ET AL), 12 February 1985 (12.02.85), column 1, line 31 - line 37; column 1, line 44 - column 2, line 33, abstract --	1-5
A	JP 2000304854 A (MITSUBISHI ELECTRIC CORP.) 20001102(abstract).Online (retrieved on 2002-08-13) Retrieved from:Paj/JPO Database. -- --------	1-5

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13 August 2002	23 -08- 2002

Name and mailing address of the ISA/	Authorized officer
Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Göran Magnusson /itw Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT
Information on patent family members

06/07/02

International application No.
PCT/SE 02/00894

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5448243 A	05/09/95	DE 4143215 A	01/07/93
		DE 59206949 D	00/00/00
		EP 0550073 A,B	07/07/93
US 4499468 A	12/02/85	NONE	